

Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation

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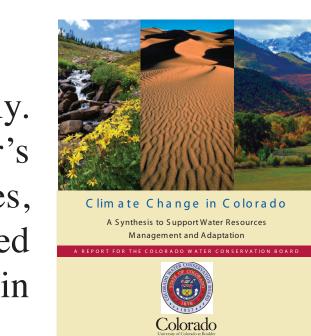
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Background

The Colorado Climate Report is a synthesis of climate change science important for Colorado's water supply. The report was commissioned by the Colorado Water Conservation Board in support of Governor Ritter's Colorado Climate Action Plan. It focuses on observed trends, modeling, and projections of temperatures, precipitation, snowmelt, and runoff. The report summarizes Colorado-specific findings from peer-reviewed regional studies, and presents new graphics derived from existing datasets. The state is home to many experts in climate and hydrology, and this report also draws from ongoing work by these scientists.



Process. For the Colorado Report, an IPCC Working Group I approach was used; the document does not specifically address adaptation and mitigation, but rather the physical science related to climate in Colorado. Drafts were made available for review by experts and stakeholders through an iterative review process, and all reviewer comments were considered by the authors. Over 500 comments were received and considered in developing the final report.

Assessment Findings

Structure. The report is divided into six sections and includes an Executive Summary, Glossary, and List of Resources. An online Appendix is also available. Throughout the report, jargon is minimized, and units are expressed as °F and ft.

Multiple independent measurements confirm widespread warming in the western United States. Changes in the water cycle will be the delivery mechanism for many impacts of climate change.

In Colorado, temperatures have increased by approximately 2°F between 1977 and 2006. Increasing temperatures are affecting the state's water resources.

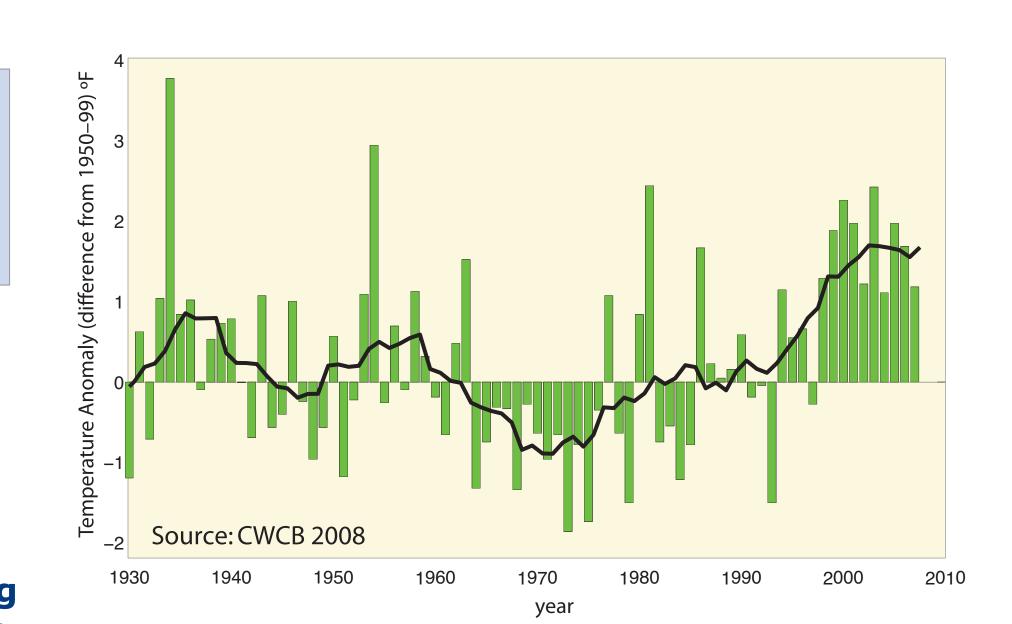
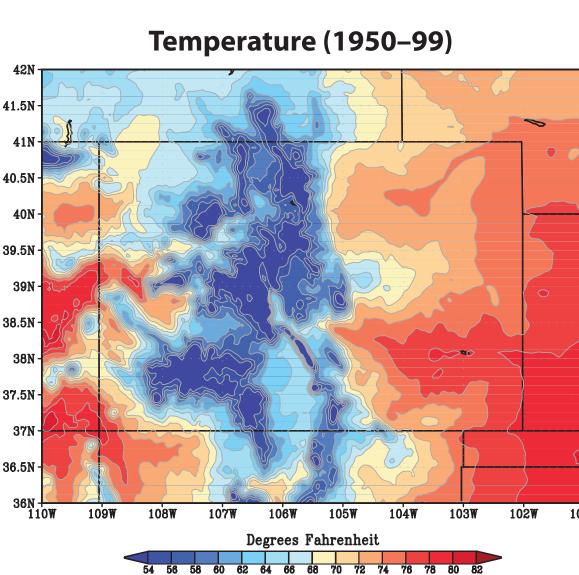
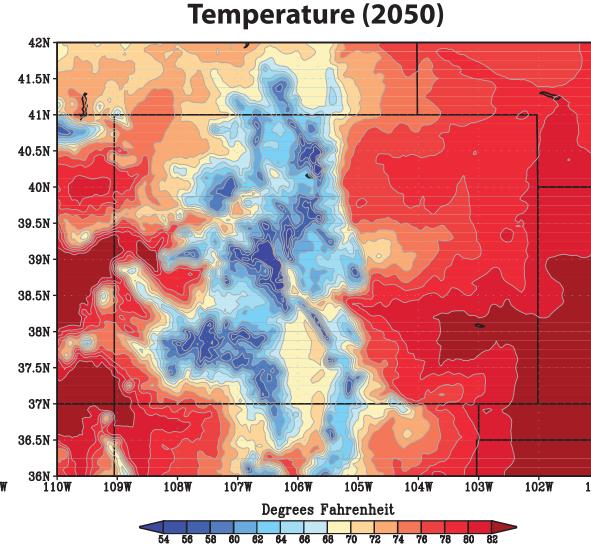


Figure 1. Colorado's Annual Average Temperatures (1930–2007)

TEMPERATURE & PRECIPITATION

Models, Scenarios, Projections. Global climate models do not represent the complexity of Colorado's topography. Researchers use techniques such as downscaling to study processes that matter to Colorado water resource managers. Several projects are underway to improve regional models. The Report includes an overview of climate models that focuses on how climate projections are developed. This section is intended to provide background for the reader about the theories behind model development, and the relationship among scenarios, models, and climate projections. Projections for 2025 and 2050 are used (when availabl) as these are the timeframes typically considered for adaptation planning.





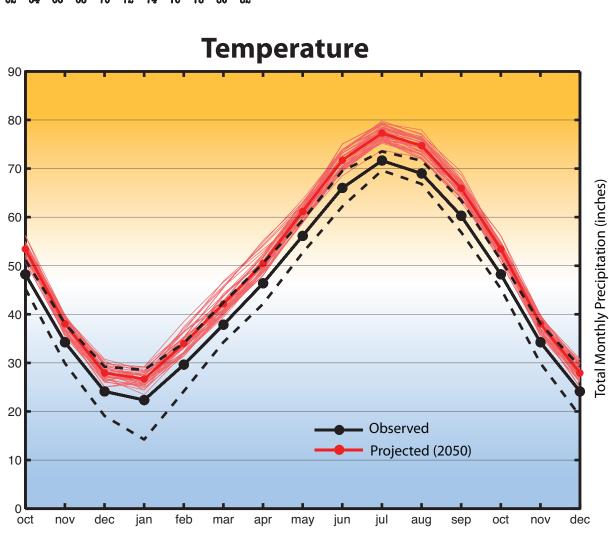
Climate models project Colorado will warm by 2.5°F by 2025 and 4°F by 2050, relative to the 1950–99 baseline (Figure 2). Mid-21st century summer temperatures on the Eastern Plains of Colorado are projected to shift westward and upslope, bringing into the Front Range temperature regimes that today occur near the Kansas border.

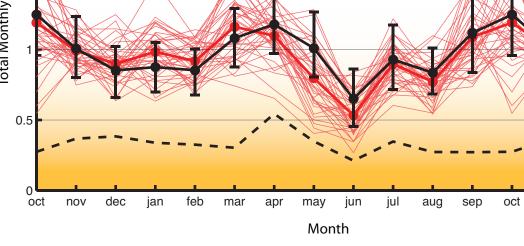
Figure 2. July Observed and Projected Temperatures in Colorado.

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Summers are projected to warm more than winters. Projections suggest that typical summer monthly temperatures will be as warm or warmer than the hottest 10% of summers that occurred between 1950 and 1999 (Figure 3).

Figure 3. Observed and Projected Monthly Temperature and Precipitation near Grand Junction, Colorado (2050)





Precipitation

Observed

Projected (2050)

Uncertainty. Recognizing the difficulty in communicating scientific uncertainty to stakeholders, climate assessments make statements designed to communicate probability. This so-called "likelihood terminology" indicates "the assessed likelihood, using expert judgment, of an outcome or a result" (IPCC 2007). The likelihood terminology quoted in this document follows two different, but similar conventions. Likelihood statements were not developed independently for this report. All likelihood statements are quoted from three major assessments: IPCC AR4 WGI 2007, IPCC 2008, and CCSP SAP 3.3.

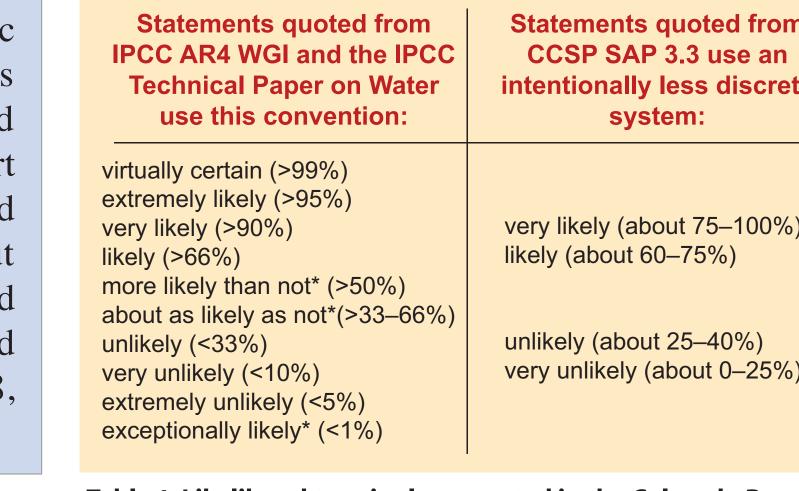


Table 1. Likelihood terminology quoted in the Colorado Report.

No consistent long-term trends in annual precipitation have been

detected in all parts of Colorado (Figure 4). Variability is high,

which makes detection of trends difficult. Climate model

projections do not agree whether annual mean precipitation will

absence of precipitation changes.

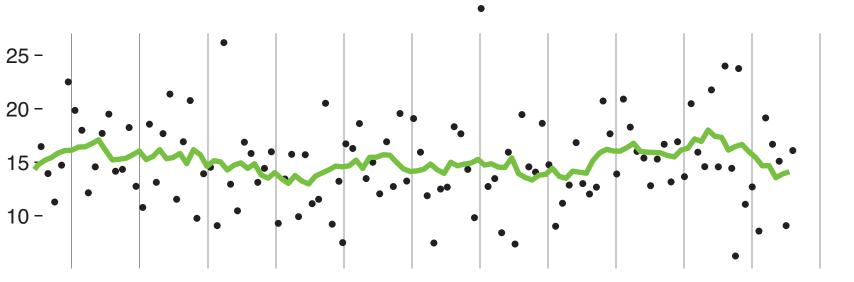


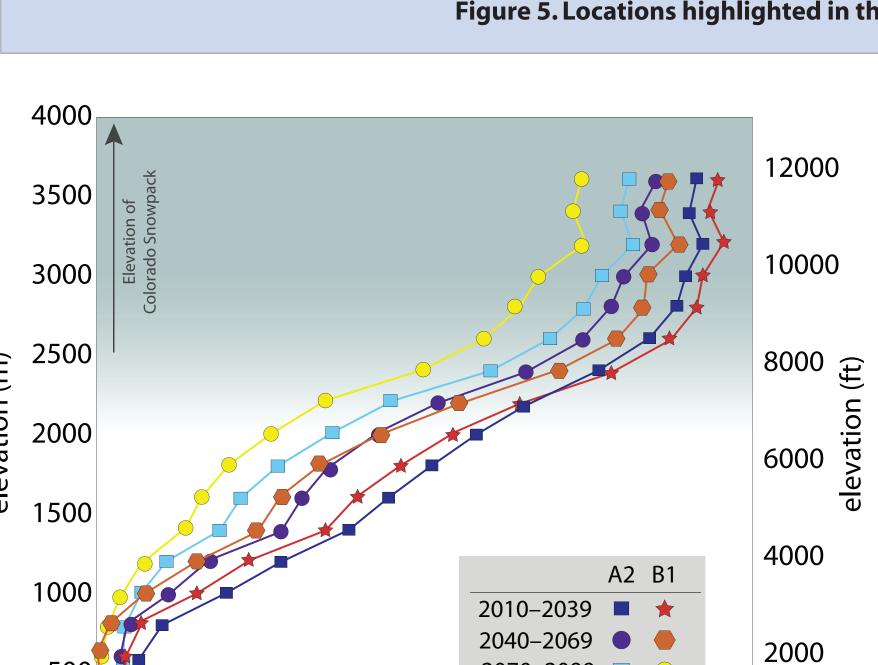
Figure 4. Precipitation trends in Fort Collins, CO.

increase or decrease by 2050.

Changes in the quantity and quality of water may occur due to warming even in the

Location, Location. A telescoping approach was taken in presenting information in the document. The Colorado Report includes climate data that are both state-wide and location specific, and places the science in the context of global observations and projections. Precipitation and temperature observations are shown for nine locations in the state, and regional temperature trends are shown for internal climate divisions. Both regional and state temperature projections are presented. Showing these different perspectives illustrates the variability across the state, while highlighting the overall warming trends.

Figure 5. Locations highlighted in the Colorado Climate Report



0 0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100% % of 1950–1999 mean

Figure 6. Projected changes in snowpack in the Colorado River Basin (Christensen & Lettenmeier 2007)

RUNOFF

Between 1978 and 2004, the spring pulse in Colorado shifted earlier by about two weeks. Several studies suggest that shifts in timing and intensity of streamflows are related to warming spring temperatures. The timing of runoff is projected to shift earlier in the spring, and late-summer flows may be reduced.

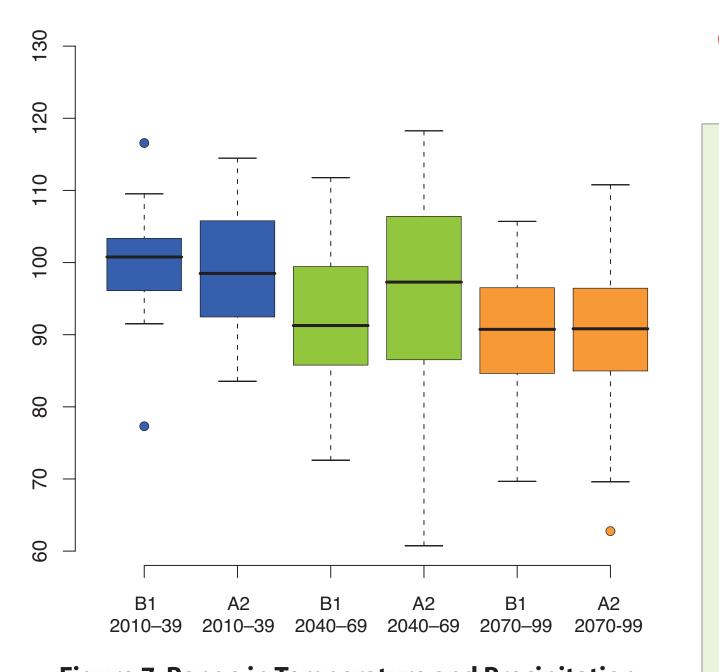
Recent hydrology projections suggest declining runoff for most of Colorado's river basins in the 21st century. However, the impact of climate change on runoff in the Rio Grande, Platte, and Arkansas Basins has not been studied as extensively as the Colorado River Basin. For the Upper Colorado River Basin, multi-model average projections suggest decreases in runoff ranging from 6% to 20% by 2050, compared to the 20th century average (Figure 7).



SNOWPACK

Most of the reduction in snowpack in the West has occurred below about 8200 ft. However, most of Colorado's snowpack is above this elevation, where winter temperatures remain well below freezing. Projections show a precipitous decline in lower-elevation (below 8200 ft) snowpack across the West by the mid-21st century. Modest declines are projected (10–20%) for Colorado's high-elecation (above 8200 ft) snowpack (Figure 6).

Climate change will affect Colorado's use and distribution of water. Water managers and planners currently face specific challenges that may be further exacerbated by projected climate change.



2010–39 2010–39 2040–69 2040–69 2070–99 2070-99

Figure 7. Range in Temperature and Precipitation Projections for the Upper Colorado River Basin

DROUGHT

Throughout the West, less frequent and less severe drought conditions have occurred during the 20th century than revealed in the paleoclimate records over the last 1000 years. Precipitation variations are the main driver of drought in Colorado and low Lake Powell inflows, including the drought of 2000–07, and these variations are consistent with the natural variability observed in long-term and paleoclimate records. However, warming temperatures may have increased the severity of droughts and exacerbated drought impacts.

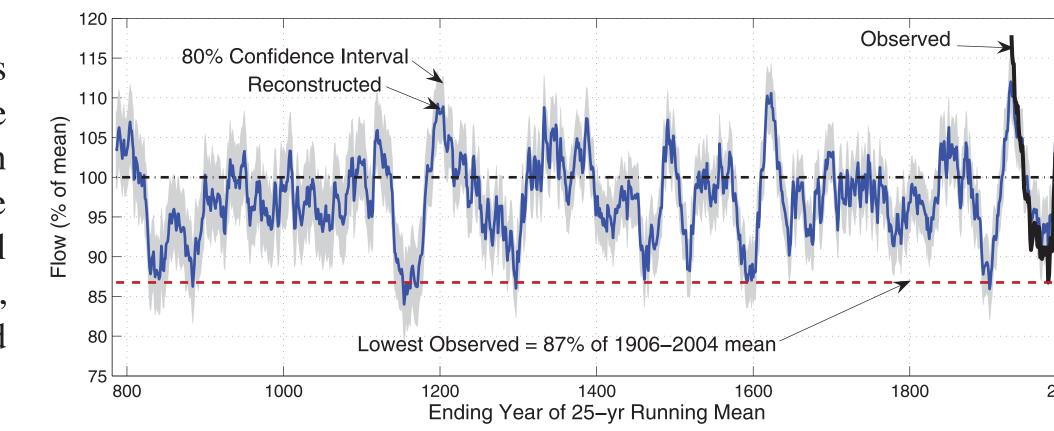


Figure 8. Paleoreconstruction of streamflow at Lees Ferry (Meko et al. 2007)

Using the Report. The Report does not specifically address adaptation and mitigation issues. However, in response to reviewer comments, we included informational boxes throughout the document that highlight how different stakeholders have used climate information in decision making. A final section of the report was added that simply outlines the different sectors that may use the information in the report in the context of impacts.

IMPLICATIONS

Table 2. Implications of physical changes in the climate system on different sectors in Colorado.

Issues	Observed and/or Projected Change
Water demands for agriculture and outdoor watering	Increasing temperatures raise evapotranspiration by plants, lower soil moisture, alter growing seasons, and thus increase water demand.
Water supply infrastructure	Changes in snowpack, streamflow timing, and hydrograph evolution may affect reservoir operations including flood control and storage. Changes in the timing and magnitude of runoff may affect functioning of diversion, storage, and conveyance structures.
Legal water systems	Earlier runoff may complicate prior appropriation systems and interstate water compacts, affecting which rights holders receive water and operations plans for reservoirs.
Water quality	Although other factors have a large impact, "water quality is sensitive both to increased water temperatures and changes in patterns of precipitation" (CCSP SAP 4.3, p. 149). For example, changes in the timing and hydrograph may affect sediment load and pollution, impacting human health.
Energy demand and operating costs	Warmer air temperatures may place higher demands on hydropower reservoirs for peaking power. Warmer lake and stream temperatures may affect water use by cooling power plants and in other industries.
Mountain habitats	Increasing temperature and soil moisture changes may shift mountain habitats toward higher elevation.
Interplay among forests, hydrology, wildfires, and pests	Changes in air, water, and soil temperatures may affect the relationships between forests, surface and ground water, wildfire, and insect pests. Water-stressed trees, for example, may be more vulnerable to pests.
Riparian habitats and fisheries	Stream temperatures are expected to increase as the climate warms, which could have direct and indirect effects on aquatic ecosystems (CCSP SAP 4.3), including the spread of in-stream non-native species and diseases to higher elevations, and the potential for non-native plant species to invade riparian areas. Changes in streamflow intensity and timing may also affect riparian ecosystems.
Water- and snow-based recreation	Changes in reservoir storage affect lake and river recreation activities; changes in streamflow intensity and timing will continue to affect rafting directly and trout fishing indirectly. Changes in the character and timing of snowpack and the ratio of snowfall to rainfall will continue to influence winter recreational activities and tourism.
Groundwater resources	Changes in long-term precipitation and soil moisture can affect groundwater recharge rates; coupled with demand issues, this may mean greater pressures on groundwater resources.

Lessons Learned & Future Directions

A model for communicating climate uncertainty on regional scales that is similar to the IPCC and CCSP models would benefit users.

Key unresolved issues and scientific gaps include groundwater, research on river basins other than the Colorado, drought attribution, and regional climate modeling.

Although there are uncertainties associated with the science assessed in this report, there is sufficient information to support adaptation planning for risks associated with climate variability and change.

References

Colorado Water Conservation Board 2008: Climate Change in Colorado, A Synthesis to Support Water Resources Management and Adaptation [A.J. Ray, J.J. Barsugli, K.B. Averyt] University of Colorado, Boulder, 52 pp.

CCSP 2008: SAP 3.3 Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and US Pacific Islands. A report by the US

Climate Change Science Program and the Subcommittee on Global Change Research. [TR Kar, GA Meehl, CD Miller, SJ Hassol, AM Waple, and WL Murray (eds.)] Washington DC, 164 pp.

IPCC 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate

Change [Solomon, S, D Qin, M Manning, Z Chen, M Marquis, K Averyt, M Tignor, HL Miller (eds.)] Cambridge University Press, New York, NY, 996 pp. IPCC 2008: Technical Paper of the Intergovernmental Panel on Climate Change, Climate Change and Water [Bates, S, ZW Kundzewicz, S Wu, JP Palutikof (eds.)] IPCC Secretariat, Geneva, 210 pp.

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